RAMAN STUDY OF CARBONACEOUS MATTER AND ANTHRAXOLITE IN ROCKS FROM THE SUDBURY, ONTARIO, IMPACT STRUCTURE. Dieter Heymann[1] and Burkhard Dressler[2], [1]Department of Geology and Geophysics, Rice University, Houston, Texas, USA; [2]Lunar and Planetary Institute, Houston, Texas, USA.

The 1.85 b.y. old Sudbury Structure in Ontario, Canada, represents the partially eroded remnant of a 200-300 km diameter multi-ring impact basin. In its center, the heterolithic impact breccias of the Black Member of the Onaping Formation and the mudstones of the Onwatin Formation contain up to ~4% finely disseminated carbonaceous matter of unknown provenance. A suggestion that it had formed by the reduction of methane during fumarolic activity [1] was considered unlikely [2]. Anthraxolite occurs as two veins up to 1.5 m wide in the Onwatin Formation. Its emplacement by “tectono-metamorphic remobilization” has been suggested [3]. Raman spectroscopy alone is unlikely to resolve the riddle of the provenance of the carbonaceous matter. However, it might be a useful first step in the right direction. A detailed investigation of the carbonaceous matter is important in the context of the reported discovery of fullerenes in the Onaping Formation [4] and will also lead to a better understanding of planetary impact processes.

Method: Perfectly crystallized macroscopic graphite has only one first-order Raman line (G-line) at 1575 cm^{-1} [5]. When the crystallite size or the size of ordered domains is reduced, for instance by grinding, a forbidden line begins to appear and grow in relative intensity (D-line) at 1355 cm^{-1} and the position of the G-line shifts to larger R-values, typically to around 1600 cm^{-1} [5]. Any significant disorder in the constancy of the distances of basal planes, or disorder within basal planes will have the same effect. Figure 1a shows the Raman Spectrum (RS) of carbonaceous matter from the CV3 meteorite Allende as an example of an RS of greatly disordered elemental carbon. This carbon does not begin to recrystallize significantly, at least on times of hours, until the temperature reaches 1000°C [6]. Carbonaceous matter from rocks of the Onaping and Onwatin Formations was obtained either by the destruction of silicates and sulfides with acids, or by the much simpler technique of ultrasonic treatment and stirring of finely powdered rock in water, which caused carbon-rich material to float. About one mg of carbon matter was secured between two circular microscope slide covers and the RS was obtained using a 488 laser beam and a SPEX spectrometer. For the anthraxolite measurement, a shiny piece of this carbon was glued onto a microscope slide and polished down to a fraction of a mm.

Results: Figure 1b shows the RS of sample SURG2 collected at High Falls. This RS is representative for the ten studied samples in Table 1. The sample locations cover a significant areal extent of the Onaping Formation. Greatly disordered carbon apparently occurs throughout most, if not all of the Onaping Formation, and perhaps the Onwatin Formation as well.Figure 2a shows the RS of the anthraxolite. Once again, this is a greatly disordered carbon, similar to the carbon in the Onaping and Onwatin rocks.

Discussion: The source for the carbonaceous material in the Onaping and Onwatin Formations is either the impactor, target rocks, metamorphic remobilization or biogenic activity. The similarities of the RS of carbon from Allende, from the rocks, and from the anthraxolite suggest an origin of the Sudbury carbons from the impactor. However, a significant fraction of the carbon of chondritic meteorites is in the form of diamonds, and we have estimated the “dilution factor” Onaping rocks/Impactor to have been at least 30, which would require an almost 100% carbon impactor! No diamonds were ever reported at Sudbury. Were they graphitized during the event?

Does the carbonaceous matter represent target rock graphite shocked by the impact? Figure 2b shows the RS of a Sri Lanka graphite shocked to 59.1 GPa [7]. In the unshocked material, the ratio of D/G is about 0.25; in the

TABLE 1. List of samples used. The carbon content was determined with a LECO apparatus.

SAMPLES	LOCATION	C CONTENT, wt%
BLACK ONAPING		
SURG2; SUBD4; SUBF6	HIGH FALLS	0.602; 0.306; 0.739
SUBD2	NELSON LAKE AREA	0.204
SUBD3; SUBF3; SUBF5	CAPREOL	1.13; 2.39; 1.06
SUGJ3	CHELMSFORD TOWNSHIP	1.83
SUGJ4	NICKEL OFFSET ROAD	1.60
ONWATIN FORMATION		
SUGJ6	ONWATIN FORMATION	2.38
ANTHRAXOLITE	N of ERRINGTON MINE	>90%

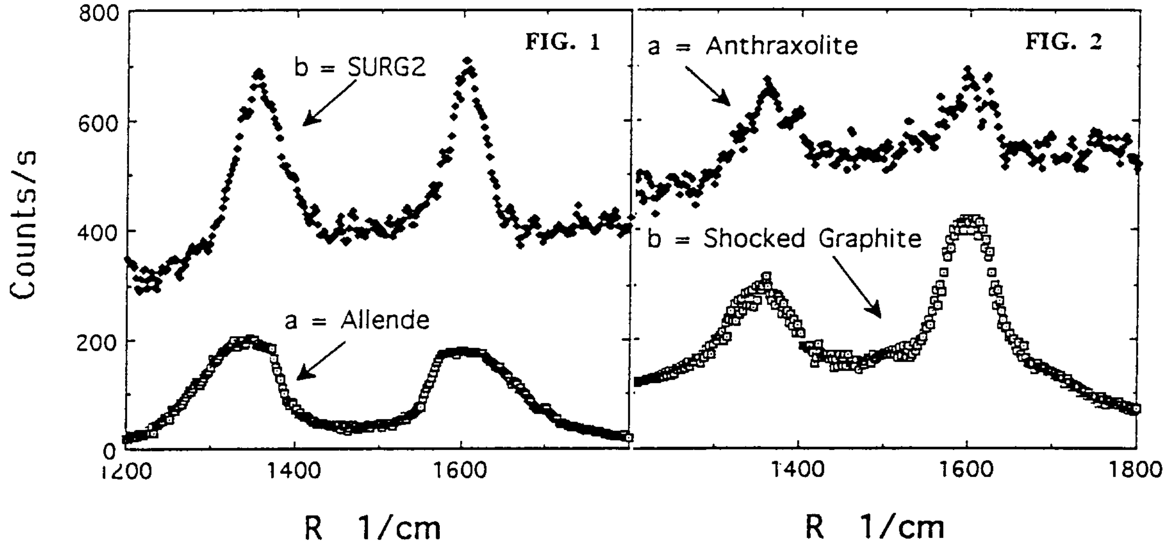

Figure 1. Raman Spectra of: a = Allende meteorite, b = carbon from rock SURG2.

Figure 2. Raman Spectra of: a = Anthraxolite, b = Sri Lanka graphite shocked to 59.1 GPa. The line at 1358 cm^{-1} is the normally forbidden D-line; the line at 1598 cm^{-1} is the blue-shifted G-line. R = Delta Wavenumber.

shocked sample it is 0.66. Based on the comparison of these results with our Sudbury data we cannot rule out that the carbon in the Sudbury Structure represents shock-altered target rock carbon. The anthraxolite, however, was emplaced after the rocks of the Onaping and Onwatin Formations, hence did not experience the shock.

The rocks of the Onwatin Formation have experienced greenschist facies metamorphism. Under such conditions, carbon with RS such as those in Figure 1 can be formed in situ from organic remains by the abstracting of H, O, S, etc. [8]. However, none of the Sudbury impact target rocks contain substantial amounts of originally organic material to account for up to 4% elemental C in the Onwatin Formation. C-bearing gases or fluids emanating from deep crustal levels and released through shock brecciation are another potential source for the carbon in the rocks of the Sudbury Structure. However, this would not explain why the carbon content of the Gray Member of the Onaping Formation is so much less than that of the Black Member which lies dirtectly above it.

References: [1] Burrows A. G. and Rickaby H. C. (1935). Ann. Rep. Ontario Dept. Mines 1934, part 2, 49p. [2] Muir T. L. and Peredery W. V. (1984). In: The geology and ore deposits of the Sudbury structure. Ministry of Natural Resources, Ontario, Canada, p. 139. [3] Rousell D. H. (1984) ibid, p. 211. [4] Becker L. et al. (1994) Science 265, 642. [5] Tuinstra F. and Koenig J. L. (1970) J. Chem. Phys. 53, 1126 [6] Heymann D. and Read N. (1987) Meteoritics 22, 229. [7] Shock loading done by F. Hoerz at JSC. [8] Pasteris J. D. and Wopenka B. (1991) Canadian Mineralogist 29, 1.